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6 "SIGNIFICANT ACCOMPLISHMENTS".

Under the

JOINT SERVICES ELECTRONICS PROGRAM

Contract 15 N00014-75-C-0632



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**SUMMARY**

**SIGNIFICANT ACCOMPLISHMENTS**

**Contract N00014-75-C-0632**

We describe briefly in the following the significant accomplishments of our program over the past year. It is difficult to rank-order these precisely, so we shall list them with some comments which would indicate our judgment of the significance of each accomplishment. In the past, we have been asked to confine ourselves to three such items. We are listing more than three because we feel that it gives a somewhat better picture of the whole program, but it is the first group of 4 projects which are probably the most significant.

1. Acoustic Microscope

There has been a project on an acoustic microscope on the JSEP program over a number of years. The emphasis in JSEP and financing from other sources has changed over this period. In the past year, the work on JSEP has been concerned with providing a design and means of operation for a microscope which would be especially suitable for looking at integrated circuits, and at getting some resolution in depth so that one could look below the surface of an integrated circuit. We had already achieved very good results on transverse resolution, i.e., spot size, with resolution of the order of a micron. In order to get resolution in depth, particularly to look at the structure below the surface of an integrated circuit, it was necessary to develop a reflection mode of operation.

It is to be noted that most of our previous work had been in transmission. This involves identical transmitters and receivers (lenses), with a common focus. Illumination by the transmitter produces a focal spot, the object is scanned through the spot and the receiver then picks up the transmitted signal. For the case of an object which has some thickness, if one is trying to look at a thin planar region and avoid any absorption or reflections produced by any intermediate portions on either side of the common focal plane between transmitter and receiver, the ordinary transmission mode is not optimum. In a reflection mode, one would use very short pulses and, by gating the receiver and transmitter, look at a particular planar region of the object. We have been able to achieve this by generating acoustic pulses of 10 nanoseconds duration. This value corresponds to a 15 micron length of the acoustic pulse in water. In turn, that means a 15 micron depth resolution. To achieve pulse lengths of this duration required the development of circuitry, including transducers, etc., with bandwidths covering a range from 250 to 450 megahertz. Pictures of integrated circuits obtained with this instrument have been much better than previously available.

We have also developed a new type of instrument in which we have 3 lenses with a common focal point, but with axes which are not colinear. In this version, we can use one lens as a transmitter of acoustic energy, a second as a receiver for the transmitted signal, and a third lens as a receiver for the reflected signal. In studying surfaces, we would monitor only the reflected signal. This configuration has the important advantage of separating the

input beam from the output beam, leading to improved sensitivity, and should also have important applications for investigating regions a small distance below the surface.

## 2. New Acoustic Imaging Techniques

A second successful project, which was listed in last year's proposal under this title, has been largely concerned with what might seem to be a very old problem, but one which has never been satisfactorily solved. It is the problem of the theoretical analysis and fabrication of transducers for launching acoustic waves for imaging, particularly arrays of such transducers where one wants the spacings to be of the order of a half wavelength. There have been very great difficulties with interaction between the transducers in such arrays, because of electrical coupling or acoustic coupling (problems with side lobes of individual transducers, etc.). There have also been severe difficulties with the fabrication of large arrays involving the machining, bonding and contacting of small, discrete transducers, especially in high resolution applications involving dimensions in the millimeter and sub-millimeter ranges. These problems result in limitations in the use of such arrays for scanning. Such acoustic imaging arrays are required for use in sonar, in systems for non-destructive testing, and in systems for medical purposes. These imaging applications involve transducer elements of fractional wavelength dimensions, because one requires the elements to have a large acceptance angle so as to be able to receive or transmit a plane wave arriving at a large angle to a normal to the array surface, perhaps as much as $\pm 30^{\circ}$.

We have been working on two types of arrays, one being the classical type involving discrete transducer elements, and the second being a new approach which allows the use of a single monolithic piezoelectric element in which the individual radiating elements are defined by deposited electrode patterns. The discrete approach involves separate rectangular transducers all bonded to a common backing, which provide a large acceptance angle but which present some problems, particularly with the frequency behavior of the elements and of the array as a whole. This is of consequence because, in many applications, it is necessary to be able to vary the frequency of the system over some range. We have made important progress on the theoretical analysis and construction of such transducers, and on understanding their frequency characteristics and the cross-coupling between them.

In the newer monolithic approach, a continuous piezoelectric strip is bonded to a suitable backing, and electrodes deposited on the piezoelectric surface are used to identify the active areas constituting the array. With proper backing, having the required acoustic as well as structural properties, one can avoid cross-coupling due to internal reflections.

We have finally been able to understand the behavior of such arrays, and to predict their characteristics, and find that one can get an acceptance angle with PZT of the order of $\pm 15^{\circ}$. We have made a 30-element array using this technique and we have tested an imaging system. The system has yielded images, and the cross-coupling does not appear to have been too severe a problem. Because of the substantial advantages of monolithic construction, we feel that this approach may become very important in future imaging systems.

3. <u>Video Bandwidth Compression Using Surface Acoustic Waves</u> and

We have been working for some period of time trying to produce surface acoustic wave storage of signals with very wide bandwidth and very long storage time. A figure of merit of such devices is given by the time bandwidth product. This is a measure of how many bits are stored and is important for any application having to do with transient data storage, correlation and convolution, transforming of data, etc. We have been able to design and test such a delay line of the so-called "wrap-around" type, in which the surface wave signal propagates along the surface of a crystal, around a cylindrical end, and continues in this way around the perimeter of the crystal in a helical path. By taking into account the various loss mechanisms, which vary with frequency in different ways, so that they can be suitably balanced over the entire bandwidth, we have been able to get a millisecond of storage for a signal 60 MHz wide (center frequency about 80 MHz). This is a time bandwidth product of 60,000 and corresponds approximately to being able to store 60,000 bits, all on a crystal about 8 inches in length. As far as we know, this constitutes the largest time bandwidth product ever obtained with this kind of storage, and also corresponds to a data rate (related to the bandwidth) which is not currently available with any other storage mechanisms such as CCDs, etc.

4. <u>Application of Acoustic Scanning to Non-Destructive Testing of Materials</u>.

In this program, we have been developing a new method of acoustic scanning which seems particularly suited for applications at high frequencies, even up to frequencies beyond 100 MHz. As far as we know, this provides scanning electronically at much higher frequencies than any other process. The method involves scattering a chirped surface acoustic wave from a diffraction grating. This latter consists of grooves cut into the surface. The surface wave is scattered by the grating into bulk waves propagating below the surface. If the surface wave is chirped, with a chirp of proper design, the various portions are scattered in different directions by the grating, and converge at some predetermined distance from the grating. This, of course, gives a line focus; then by using an integral cylindrical lens at right angles to this line, the line can be focused to a point. This whole system of rays, and the focal spot, then move along the scanned region at the velocity of the surface wave on the original scattering surface. Thus, one gets focusing and scanning, the scanning being done at a velocity of the order of thousands of meters per second (typical surface wave velocities). By changing the chirp rate, one changes the convergence of the acoustic wave and therefore, one can change focal length and thus the range at which scanning takes place. This was done at about 2.3 megahertz center frequency, and gave a resolution of about 5 millimeters. The concept can be extended up to 100 megahertz, and substantially higher, if desirable.

5. <u>Other Projects</u>

As a second group of accomplishments, we list several projects which are also significant but probably not as far along in actual achievement.

a. <u>Study of Acoustic Wave Propagation in Poly Vinylidene Fluoride</u>

An investigation has been made of the piezoelectric properties of a piezoelectric plastic film known as poly vinylidene fluoride. It has been known to be piezoelectric, but no one up until now has measured its properties. We have measured its piezoelectric coupling coefficient, its Q at about 40 megahertz, and now know much more about its properties than was hitherto available. This plastic thin film can have important implications in non-destructive testing because it can be used as a transducing material, over very irregular surfaces, merely by cementing it down. It is cheap, comes in very wide sheets, and an understanding of its properties is obviously important for reasons just stated.

b. <u>Optical Scanning Microscope</u>

The major achievement has really been in the form of an invention which has not yet been reduced to practice. The proposal on a laser scanning microscope stated what would be the advantages and possible applications of using a coherent light source (a laser) in a microscope. The high intensity one can obtain at a focal spot, assuming pulsed operation, would lead to various kinds of biological and technological experiments which made use of the high intensity-nonlinear effects, such as Raman, etc. In the course of this year, a particular design has evolved. A paraboloidal reflector as the lens system will produce a focal spot if illuminated with a parallel beam. The object could be scanned through the plane containing the focal spot. The interesting aspect of this is that such a system could operate even into the extreme ultraviolet, at any frequency for which sources exist. One can now get wavelengths as short as 800Å and can think of going to shorter wavelengths. This will provide a microscope which can be used up to this wavelength. Fabrication problems do not seem to be unusually difficult.

c. <u>Studies of the Electrical Behavior of Superconducting Quantum Devices using High-$T_c$ Materials</u>

We have produced the first junctions ever made with $Nb_3Sn$ and $Nb_3Ge$ which show Josephson tunneling.